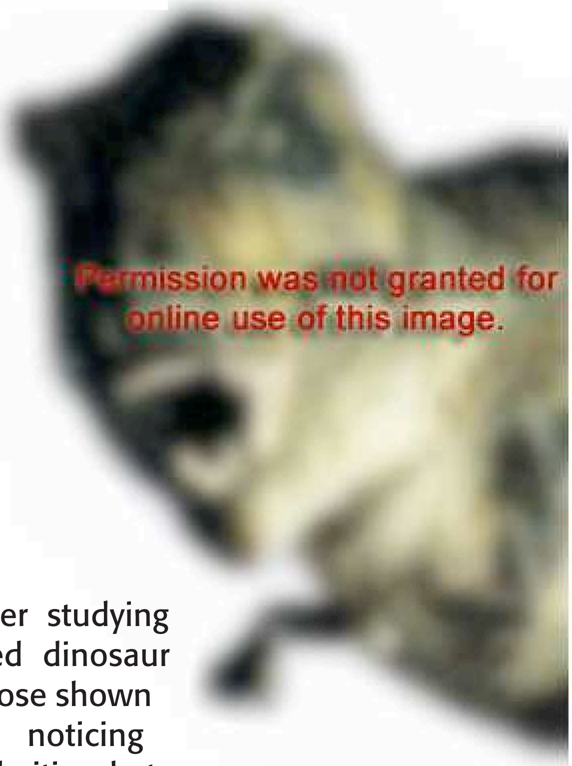
CHAPTER

12 Introduction to Atoms



Would You Believe . . . ?

Tiny atoms have something in common with huge dinosaurs. In both cases, scientists have had to try to understand something they could not observe firsthand!

No one has ever seen a living dinosaur. So how did the special-effects crew for the movie *Jurassic Park* know what the *Tyrannosaurus rex* model, shown above, should look like? Scientists have determined the appearance of *T. rex* by studying fossilized skeletons. Based on fossil evidence, scientists theorize that these now-extinct creatures had big hind legs, small front legs, a long whip-like tail, and an enormous mouth full of dagger-shaped teeth.

However, theories of how *T. rex* walked have been harder to develop because there is no way to see a dinosaur in motion. For many years, most scientists thought that *T. rex* (and all dinosaurs) plodded slowly like big, lazy lizards.

However, after studying well-preserved dinosaur tracks, like those shown below, and noticing skeletal similarities between certain dinosaur fossils and living creatures such as the ostrich, many scientists now theorize that *T. rex* and its dinosaur cousins could turn on the speed. Some scientists estimate that *T. rex* had bursts of speed of 32 km/h (20 mi/h)!

Theories about *T. rex* and other dinosaurs have changed gradually over many years based on indirect evidence, such as dinosaur tracks. Likewise, our theory of the atom has changed and grown over thousands of years as scientists have uncovered more evidence about the atom, even though they were unable to see an atom directly. In this chapter, you'll learn about the development of the atomic theory and our current understanding of atomic structure.

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Where Is It?

Theories about the internal structure of atoms were developed by aiming moving particles at atoms. In this activity you will develop an idea about the location and size of a hidden object by rolling marbles at the object.

Procedure

1. Place a rectangular piece of **cardboard** on **four books or blocks** so that each corner of the cardboard rests on a book or block.
2. Ask your teacher to place the **unknown object** under the cardboard. Be sure that you do not see it.
3. Place a **large piece of paper** on top of the cardboard.
4. Gently roll a **marble** under the cardboard, and record on the paper the position where the marble enters and exits and the direction it travels.
5. Continue rolling the marble from different directions to determine the shape and location of the object.
6. Write down all your observations in your ScienceLog.

Analysis

7. Form a conclusion about the object's shape, size, and location. Record your conclusion in your ScienceLog.

What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. What are some ways that scientists have described the atom?
2. What are the parts of the atom, and how are they arranged?
3. How are atoms of all elements alike?

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Section 1

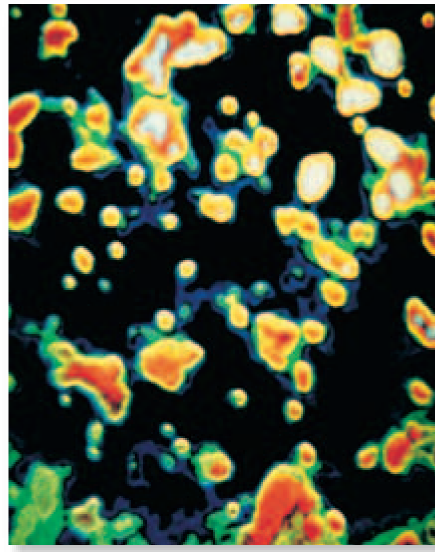
Development of the Atomic Theory

NEW TERMS

atom
theory
electrons
model
nucleus
electron clouds

OBJECTIVES

- Describe some of the experiments that led to the current atomic theory.
- Compare the different models of the atom.
- Explain how the atomic theory has changed as scientists have discovered new information about the atom.



The photo at right shows uranium atoms magnified 3.5 million times by a scanning tunneling microscope. An **atom** is the smallest particle into which an element can be divided and still be the same substance. Atoms make up elements; elements combine to form compounds. Because all matter is made of elements or compounds, atoms are often called the building blocks of matter.

Before the scanning tunneling microscope was invented, in 1981, no one had ever seen an atom. But the existence of atoms is not a new idea. As you will find out, our understanding of atoms has been developing for more than 2,000 years. How is this possible? The answer has to do with theories. A **theory** is a unifying explanation for a broad range of hypotheses and observations that have been supported by testing. In this section, you will take a short trip through history to see for yourself how our understanding of atoms developed even before we could observe them directly. Your first stop—ancient Greece.

Figure 1 *Democritus thought the smallest particle in an object like this silver coin was an atom. This coin was in use during Democritus's time.*

Democritus Proposes the Atom

Look at the silver coin shown in **Figure 1.** Imagine that you cut the coin in half, then cut those halves in half, and so on. Could you keep cutting the pieces in half forever, or would you eventually end up with a particle that you could not cut?

Around 440 B.C., a Greek philosopher named Democritus (di MAHK ruh tuhs) proposed that in such a situation, you would end up with an "uncuttable" particle. He called this particle an *atom* (from the Greek word *atomos,* meaning "indivisible"). Democritus proposed that all atoms are small, hard particles made of a single material formed into different shapes and sizes. He also claimed that atoms are always moving and that they form different materials by joining together.

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Aristotle (ER is TAHT uhl), a Greek philosopher who lived from 384 to 322 B.C., disagreed with Democritus's ideas. He believed that you could keep cutting an object in half over and over and never end up with an indivisible particle. Although Aristotle's ideas were eventually proved incorrect, he had such a strong influence on popular belief that Democritus's ideas were largely ignored for centuries.

Dalton Creates an Atomic Theory Based on Experiments

By the late 1700s, scientists had learned that elements combine in specific proportions to form compounds. These proportions are based on the mass of the elements in the compounds. For example, hydrogen and oxygen always combine in the same proportion to form water. John Dalton, a British chemist and school teacher, wanted to know why. He performed experiments with different substances. His results demonstrated that elements combine in specific proportions because they are made of individual atoms. After many experiments and observations, Dalton, shown in **Figure 2,** published his own atomic theory in 1803. His theory stated the following:

- **All substances are made of atoms. Atoms are small particles that cannot be created, divided, or destroyed.**
- **Atoms of the same element are exactly alike, and atoms of different elements are different.**
- **Atoms join with other atoms to make new substances.**

It took many years for scientists to accept Dalton's atomic theory, but toward the end of the nineteenth century scientists agreed that his theory explained many of their observations. However, as new information was discovered that could not be explained by Dalton's ideas, the atomic theory changed. The theory was revised to more correctly explain the atom. As you read on, you will learn how Dalton's theory has changed, step by step, into the current atomic theory.

BRAIN FOOD

In 342 or 343 B.C., King Phillip II of Macedon appointed Aristotle to be a tutor for his son, Alexander. Alexander later conquered Greece and the Persian Empire (in what is now Iran) and became known as Alexander the Great.

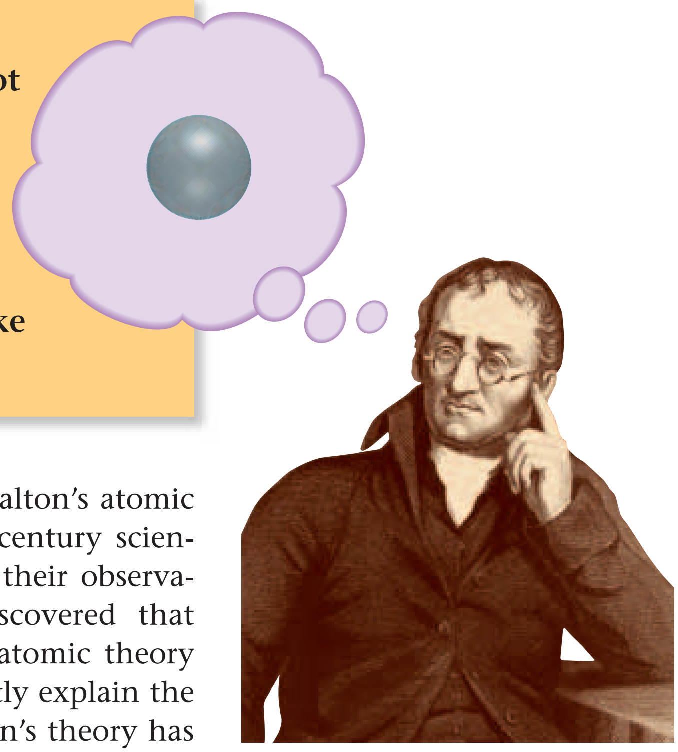

Figure 2 *John Dalton developed his atomic theory from observations gathered from many experiments.*

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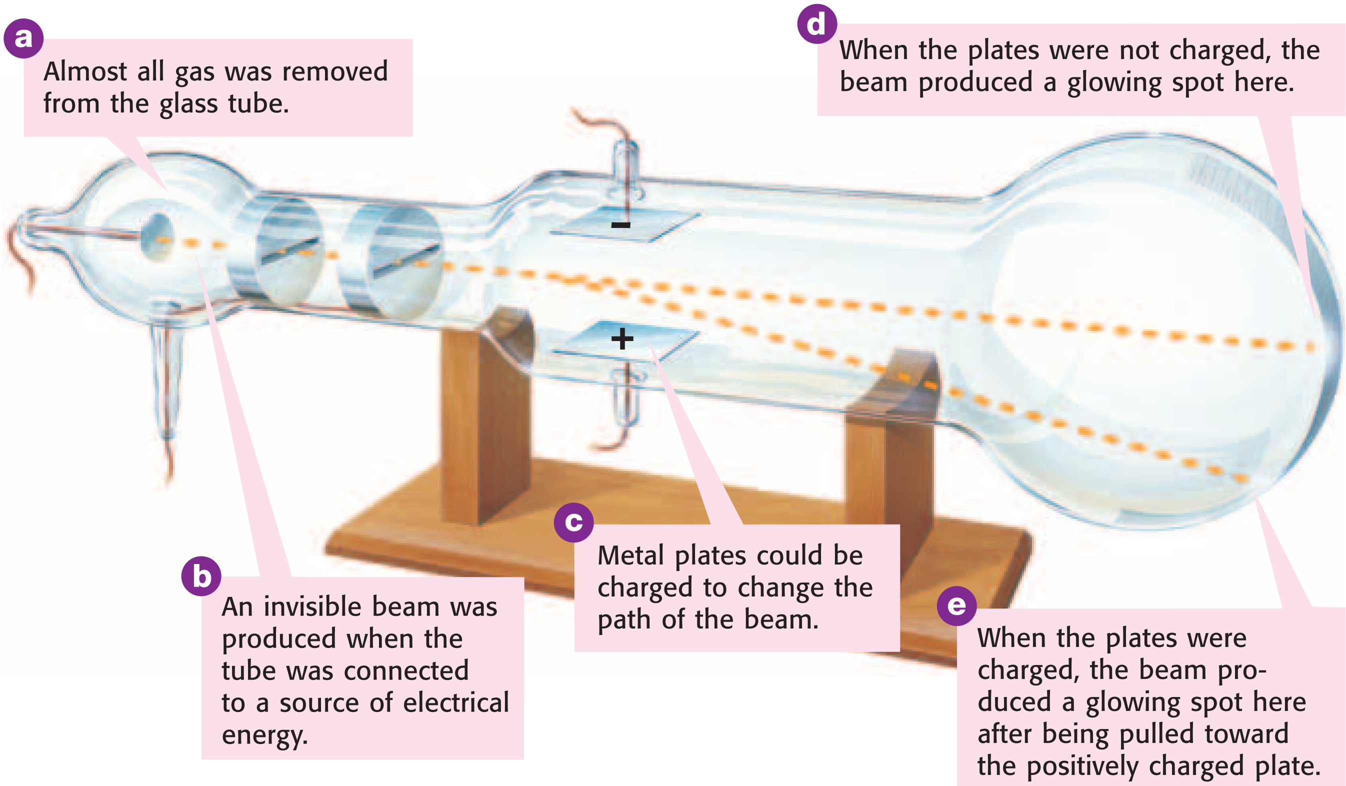
Thomson Finds Electrons in the Atom

In 1897, a British scientist named J. J. Thomson made a discovery that identified an error in Dalton's theory. Using relatively simple equipment (compared with modern scientific equipment), Thomson discovered that there are small particles *inside* the atom. Therefore, atoms can be divided into even smaller parts. Atoms are not indivisible, as proposed by Dalton.

Thomson experimented with a cathode-ray tube, as shown in **Figure 3.** He discovered that the direction of the beam was affected by electrically charged plates. Notice in the illustration that the plate marked with a positive sign, which represents a positive charge, attracts the beam. Because the beam was pulled toward a positive charge, Thomson concluded that the beam was made of particles with a negative electric charge.

Figure 3 Thomson's Cathode-Ray Tube Experiment



Just What Is Electric Charge?

Have you ever rubbed a balloon on your hair? The properties of your hair and the balloon seem to change, making them attract one another. To describe these observations, scientists say that the balloon and your hair become "charged." There are two types of charges, positive and negative. Objects with opposite charges attract each other, while objects with the same charge push each other away. When Thomson observed that the beam was pulled toward a positively charged plate, he concluded that the particles in the beam must be negatively charged.

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Thomson repeated his experiment several times and found that the particle beam behaved in exactly the same way each time. He called the particles in the beam corpuscles (KOR PUHS uhls). His results led him to conclude that corpuscles are present in every type of atom and that all corpuscles are identical. The negatively charged particles found in all atoms are now called **electrons.**

Like Plums in a Pudding Thomson knew that electrons were a part of atoms and that Dalton's belief that atoms could not be divided was therefore incorrect. Thomson revised the atomic theory to account for the presence of electrons, but he still did not know how electrons are arranged inside atoms. In addition, chemists knew that atoms have no overall charge, so Thomson realized that positive charges must be present to balance the negative charges of the electrons. But just as Thomson didn't know the location of the electrons, he didn't know the location of the positive charges. He proposed a model to describe a possible structure of the atom. A **model** is a representation of an object or system. A model is different from a theory in that a model presents a picture of what the theory explains.

In Thomson's model, illustrated in **Figure 4,** the atom is a positively charged blob of material with electrons scattered throughout. This model came to be known as the plum-pudding model, named for an English dessert that was popular at the time. The electrons could be compared to the plums that were found throughout the pudding. Today you might call Thomson's model the chocolate-chip-ice-cream model; electrons in the atom could be compared to the chocolate chips found throughout the ice cream!

BRAIN FOOD

The word *electron* comes from a Greek word meaning "amber." The ancient Greeks knew that a piece of amber (the solidified sap from ancient trees) could attract small bits of straw and paper after being rubbed with cloth.

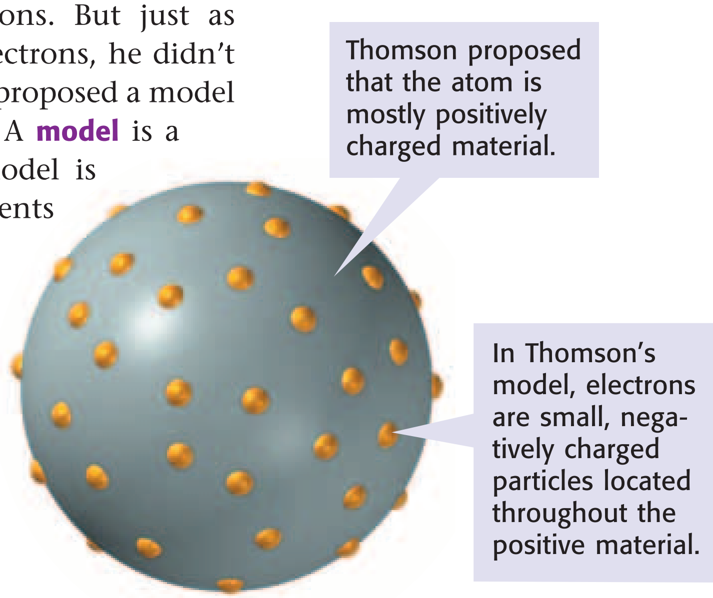

Figure 4 *Thomson's plum-pudding model of the atom is shown above. A modern version of Thomson's model might be chocolate-chip ice cream.*

REVIEW

1. What discovery demonstrated that atoms are not the smallest particles?
2. What did Dalton do in developing his theory that Democritus did not do?
3. **Analyzing Methods** Why was it important for Thomson to repeat his experiment?

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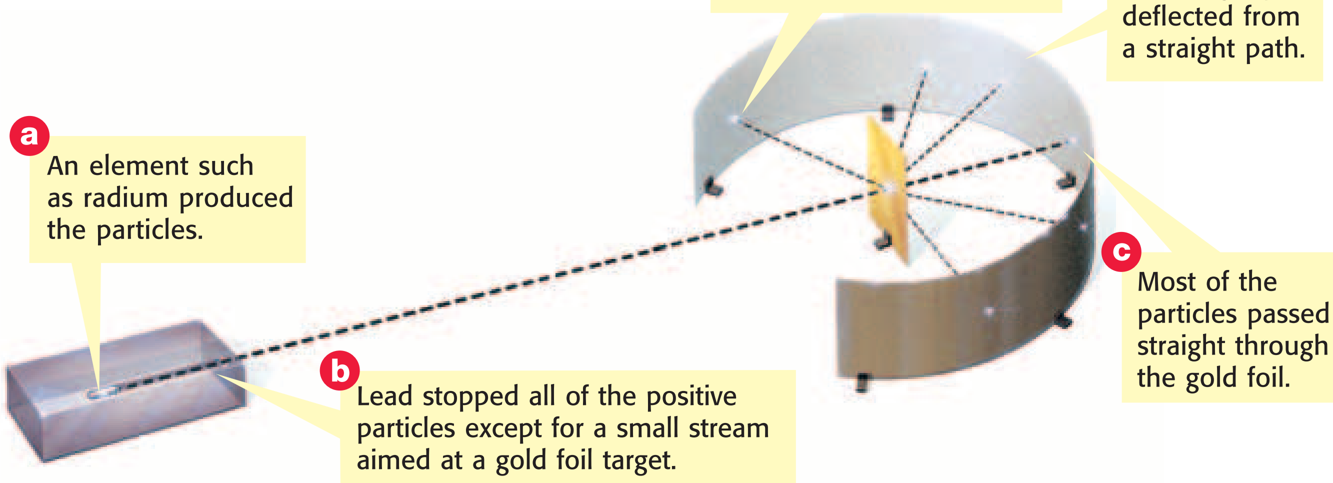
Rutherford Opens an Atomic "Shooting Gallery"

Find out about Melissa Franklin, a modern atom explorer, on page 323.

In 1909, a former student of Thomson's named Ernest Rutherford decided to test Thomson's theory. He designed an experiment to investigate the structure of the atom. He aimed a beam of small, positively charged particles at a thin sheet of gold foil. These particles were larger than *protons,* even smaller positive particles identified in 1902. Even though the gold foil was thinner than the foil used to wrap a stick of chewing gum, it was still about 10,000 atoms thick! **Figure 5** shows a diagram of Rutherford's experiment. To find out where the particles went after being "shot" at the gold foil, Rutherford surrounded the foil with a screen coated with zinc sulfide, a substance that glowed when struck by the particles.

Figure 5 Rutherford's Gold Foil Experiment



Rutherford thought that if atoms were soft "blobs" of material, as suggested by Thomson, then the particles would pass through the gold and continue in a straight line. Most of the particles did just that. But to Rutherford's great surprise, some of the particles were deflected (turned to one side) a little, some were deflected a great deal, and occasionally a particle seemed to bounce back. When describing his amazement, Rutherford reportedly said,

"It was quite the most incredible event that has ever happened to me in my life. It was almost as if you fired a fifteen-inch shell into a piece of tissue paper and it came back and hit you."

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Rutherford Presents a New Atomic Model It was obvious to Rutherford that the plum-pudding model of the atom did not explain his results. In 1911, he revised the atomic theory. Rutherford concluded that because almost all of the particles had passed through the gold foil, atoms are mostly empty space. He proposed that the lightweight, negative electrons move in the empty space.

To explain the deflection of the other particles, Rutherford proposed that in the center of the atom is a tiny, extremely dense, positively charged region called the **nucleus** (NOO klee uhs). The Rutherford model is illustrated in **Figure 6.** From the results of his experiment, Rutherford reasoned that positively charged particles that passed close by the nucleus were pushed away from their straight-line path by the positive charges in the nucleus. (Remember, opposite charges attract, and like charges repel.) Occasionally, a particle would head straight for a nucleus and be pushed almost straight back in the direction from which it came.

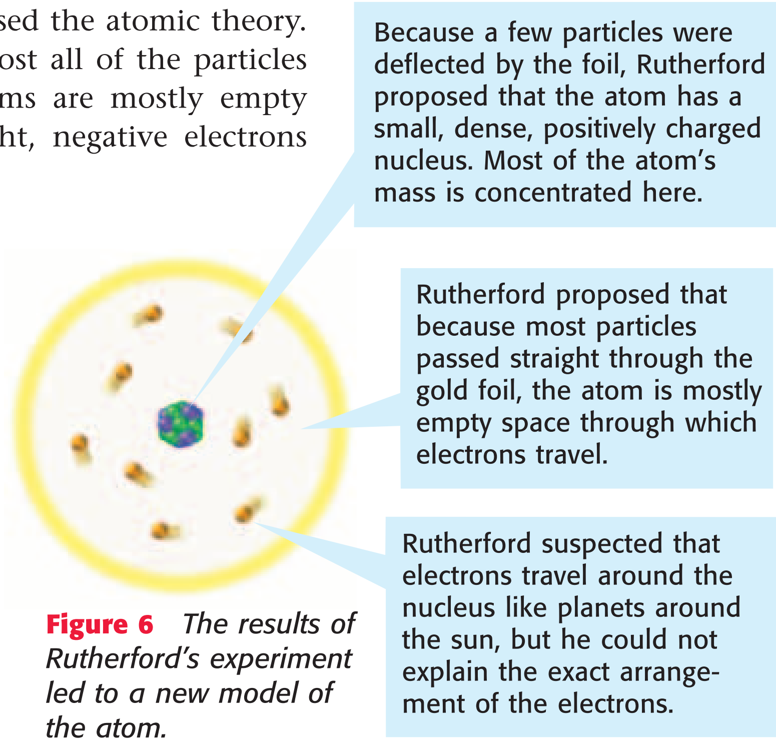

Figure 6 *The results of Rutherford's experiment led to a new model of the atom.*

From the results of Rutherford's experiment, he calculated that the diameter of the nucleus was 100,000 times smaller than the diameter of the gold atom. To imagine how small this is, look at **Figure 7.**

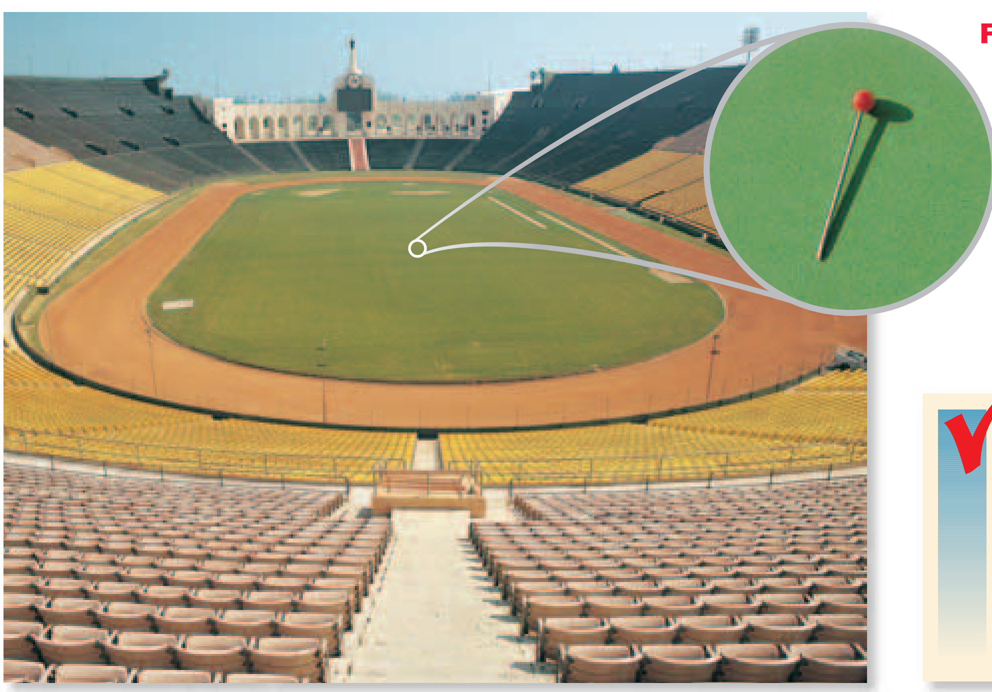

Figure 7 *The diameter of this pinhead is 100,000 times smaller than the diameter of the stadium. Likewise, the diameter of a nucleus is 100,000 times smaller than the diameter of an atom.*

Self-Check

Why did Thomson believe the atom contains positive charges? *(See page 596 to check your answer.)*

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Bohr States That Electrons Can Jump Between Levels

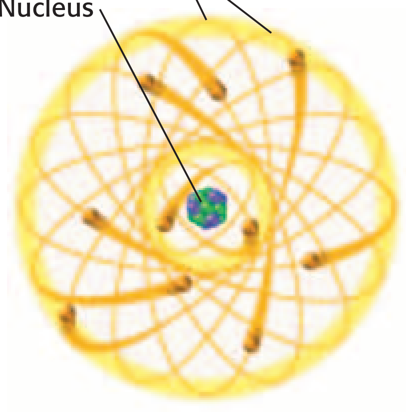

Figure 8 *Bohr proposed that electrons move in paths at certain distances around the nucleus.*

The next step in understanding the atom came just 2 years later, from a Danish scientist who worked with Rutherford. In 1913, Niels Bohr suggested that electrons travel around the nucleus in definite paths. These paths are located in levels at certain distances from the nucleus, as illustrated in **Figure 8.** Bohr proposed that no paths are located between the levels, but electrons can jump from a path in one level to a path in another level. Think of the levels as rungs on a ladder. You can stand *on* the rungs of a ladder but not *between* the rungs.

Bohr's model was a valuable tool in predicting some atomic behavior. But the model was too simple to explain all of the behavior of atoms, so scientists continued to study the atom and improve the atomic theory.

The Modern Theory: Electron Clouds Surround the Nucleus

Many twentieth-century scientists have contributed to our current understanding of the atom. An Austrian physicist named Erwin Schrödinger (1887–1961) and a German physicist named Werner Heisenberg (1901–1976) made particularly important contributions. Their work further explained the nature of electrons in the atom. For example, electrons do not travel in definite paths as Bohr suggested. In fact, the exact path of a moving electron cannot be predicted. According to the current theory, there are regions inside the atom where electrons are *likely* to be found—these regions are called **electron clouds.** Electron clouds are related to the paths described in Bohr's model. The electron-cloud model of the atom is illustrated in **Figure 9.**

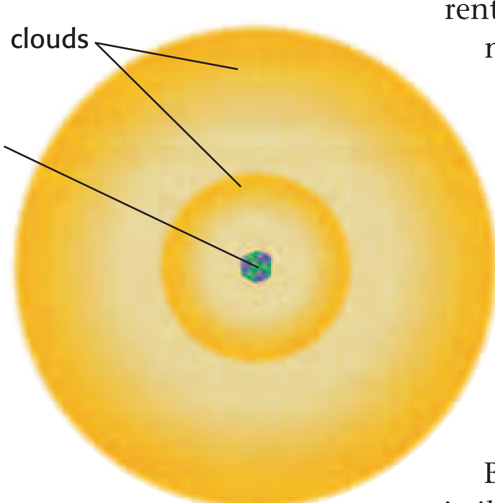

Figure 9 *In the current model of the atom, regions of the atom called electron clouds are the most likely places to find electrons.*

REVIEW

1. In what part of an atom is most of its mass located?
2. What are two differences between the atomic theory described by Thomson and that described by Rutherford?
3. **Comparing Concepts** Identify the difference in how Bohr's theory and the modern theory describe the location of electrons.

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Section 2

The Atom

NEW TERMS

protons
atomic mass unit (amu)
neutrons
atomic number
isotopes
mass number
atomic mass

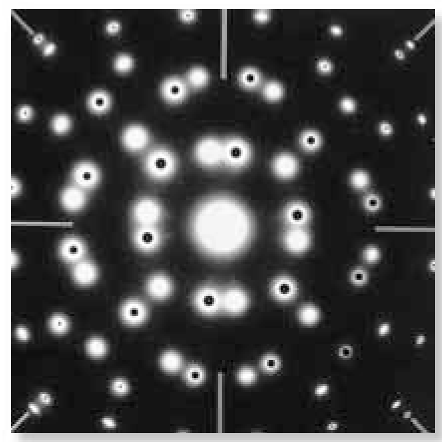
OBJECTIVES

- Compare the charge, location, and relative mass of protons, neutrons, and electrons.
- Calculate the number of particles in an atom using the atomic number, mass number, and overall charge.
- Calculate the atomic mass of elements.

In the last section, you learned how the atomic theory developed through centuries of observation and experimentation. Now it's time to learn about the atom itself. In this section, you'll learn about the particles inside the atom, and you'll learn about the forces that act on those particles. But first you'll find out just how small an atom really is.

How Small Is an Atom?

The photograph below shows the pattern that forms when a beam of electrons is directed at a sample of aluminum. By analyzing this pattern, scientists can determine the size of an atom. Analysis of similar patterns for many elements has shown that aluminum atoms, which are average-sized atoms, have a diameter of about 0.00000003 cm. That's three hundred-millionths of a centimeter. That is so small that it would take a stack of 50,000 aluminum atoms to equal the thickness of a sheet of aluminum foil from your kitchen!



As another example, consider an ordinary penny. Believe it or not, a penny contains about 2×10^{22} atoms, which can be written as 20,000,000,000,000,000,000,000 atoms, of copper and zinc. That's twenty thousand billion billion atoms—4,000,000,000,000 times more atoms than there are people on Earth! So if there are that many atoms in a penny, each atom must be very small. You can get a better idea of just how small an atom is in **Figure 10.**

Figure 10 *If you could enlarge a penny until it was as wide as the continental United States, each of its atoms would be only about 3 cm in diameter—about the size of this table-tennis ball.*

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What's Inside an Atom?

As tiny as an atom is, it consists of even smaller particles—protons, neutrons, and electrons—as shown in the model in **Figure 11.** (The particles represented in the figures are not shown in their correct proportions because the electrons would be too small to see.) Protons and neutrons make up the nucleus, which is the center of the atom. Electrons are found outside the nucleus.

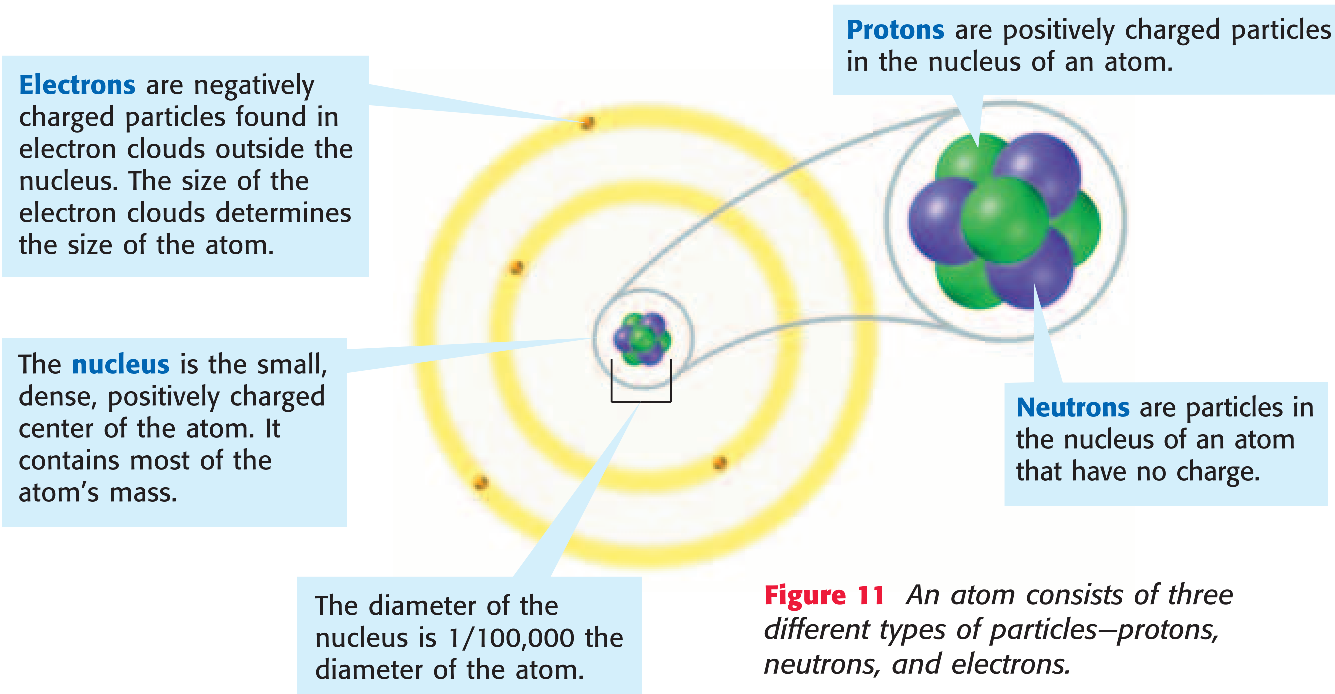

Figure 11 *An atom consists of three different types of particles—protons, neutrons, and electrons.*

The Nucleus **Protons** are the positively charged particles of the nucleus. It was these particles that repelled Rutherford's "bullets." All protons are identical, and each proton has a positive charge. The mass of a proton is approximately 1.7×10^{-24}g, which can also be written as 0.0000000000000000000000017g. Because the masses of particles in atoms are so small, scientists developed a unit of measurement for them. The SI unit used to measure the masses of particles in atoms is the **atomic mass unit (amu).** Scientists assigned each proton a mass of 1 amu.

Neutrons are the particles of the nucleus that have no charge. All neutrons are identical. Neutrons are slightly more massive than protons, but the difference in mass is so small that neutrons are also given a mass of 1 amu.

Protons and neutrons are the most massive particles in an atom, yet the nucleus they form has a very small volume. In other words, the nucleus is very dense. In fact, if it were possible for a nucleus to have a volume of 1 cm^3—the volume of an average grape—that nucleus would have a mass greater than 9 million metric tons!

Particle Profile
Name: proton
Charge: positive
Mass: 1 amu
Location: nucleus

Particle Profile
Name: neutron
Charge: none
Mass: 1 amu
Location: nucleus

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Outside of the Nucleus *Electrons* are the negatively charged particles in atoms. The current atomic theory states that electrons are found moving around the nucleus within electron clouds. The charges of protons and electrons are opposite but equal in size. Therefore, whenever there are equal numbers of protons and electrons, their charges cancel out. An atom has no overall charge and is described as being neutral. If the number of electrons is different from the number of protons, the atom becomes a charged particle called an *ion* (IE ahn). Ions are positively charged if the protons outnumber the electrons, and they are negatively charged if the electrons outnumber the protons.

Electrons are very small in mass compared with protons and neutrons. It takes more than 1,800 electrons to equal the mass of 1 proton. In fact, the mass of an electron is so small that it is usually considered to be zero.

Particle Profile
Name: electron
Charge: negative
Mass: almost zero
Location: electron clouds

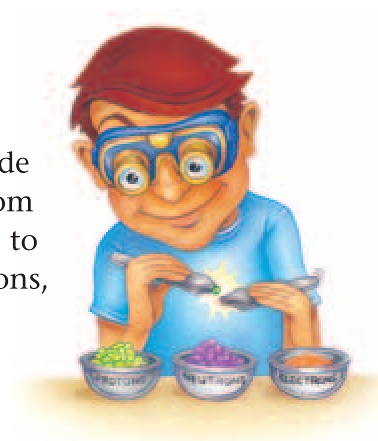
REVIEW

1. What particles form the nucleus?
2. Explain why atoms are neutral.
3. **Summarizing Data** Why do scientists say that most of the mass of an atom is located in the nucleus?

LabBook

Help wanted! Elements-4-U needs qualified nucleus builders. Report to page 570 of the LabBook.

How Do Atoms of Different Elements Differ?



There are 112 different elements, each of which is made of different atoms. What makes atoms different from each other? To find out, imagine that it's possible to "build" an atom by putting together protons, neutrons, and electrons.

It's easiest to start with the simplest atom. Protons and electrons are found in all atoms, and the simplest atom consists of just one of each. It's so simple it doesn't even have a neutron. Put just one proton in the center of the atom for the nucleus. Then put one electron in the electron cloud, as shown in the model in **Figure 12.** Because positive and negative charges in this atom cancel each other out, your atom is neutral. Congratulations! You have just made the simplest atom—a hydrogen atom.

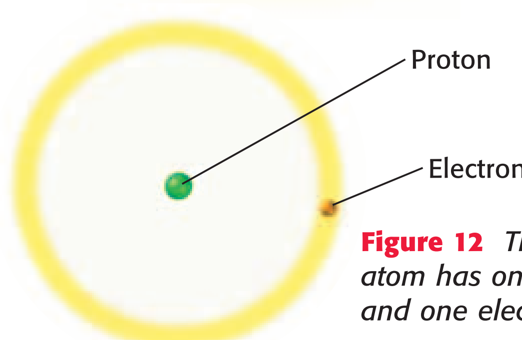


Figure 12 *The simplest atom has one proton and one electron.*

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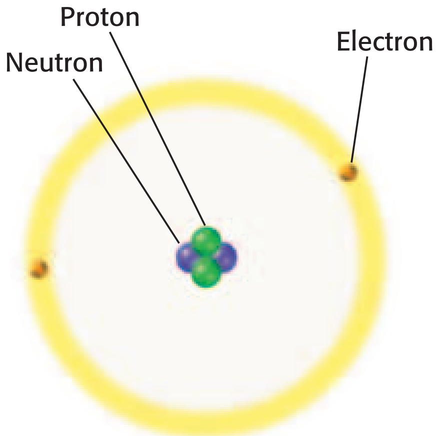

Figure 13 *A helium nucleus must have neutrons in it to keep the protons from moving apart.*

Now for Some Neutrons Now build an atom containing two protons. This time you will find that you must have some neutrons around to hold the protons together. Both of the protons are positively charged, so they repel one another. You cannot cram them together to form a nucleus unless you put some neutrons there to counteract the repulsion. For this atom, two neutrons will do. Your new atom will have two protons and two neutrons making up the nucleus and two electrons zipping around outside the nucleus, as shown in the model in **Figure 13.** This is an atom of the element helium.

You could continue combining particles, building all of the 112 known elements. You could build a carbon atom using 6 protons, 6 neutrons, and 6 electrons; you could build an oxygen atom using 8 protons, 9 neutrons, and 8 electrons; or you could build an iron atom using 26 protons, 30 neutrons, and 26 electrons. You could even build a gold atom with 79 protons, 118 neutrons, and 79 electrons! As you can see, an atom does not have to have equal numbers of protons and neutrons.

astronomy CONNECTION

Hydrogen is the most abundant element in the universe. It is the fuel for the sun and other stars. It is currently believed that there are roughly 2,000 times more hydrogen atoms than oxygen atoms and 10,000 times more hydrogen atoms than carbon atoms.

The Number of Protons Determines the Element How can you tell which elements these atoms represent? The key is the number of protons. The number of protons in the nucleus of an atom is the **atomic number** of that atom. Each element is composed of atoms that all have the same atomic number. Every hydrogen atom has only one proton in its nucleus, so hydrogen has an atomic number of 1. Every carbon atom has six protons in its nucleus, so carbon has an atomic number of 6.

Are All Atoms of an Element the Same?

Imagine you're back in the atom-building workshop. This time you'll make an atom that has one proton, one electron, and one neutron, as shown in **Figure 14.** This new atom has one proton—what does that tell you? Its atomic number is 1, so it is hydrogen. This atom is neutral because there are equal numbers of protons and electrons. However, this hydrogen atom's nucleus has two particles; therefore, this atom has a greater mass than the first hydrogen atom you made. What you have is another isotope (IE suh TOHP) of hydrogen.

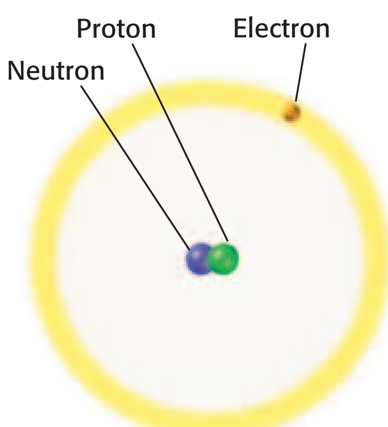

Figure 14 *The atom in this model and the one in Figure 12 are isotopes because each has one proton but a different number of neutrons.*

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Isotopes are atoms that have the same number of protons but have different numbers of neutrons. Each element has a limited number of isotopes that occur naturally. Atoms that are isotopes of each other are always the same element because the number of protons in each atom is the same.

Some isotopes of an element have unique properties because they are unstable. An unstable atom is an atom whose nucleus can change its composition. This type of isotope is *radioactive*. However, isotopes of an element share most of the same chemical and physical properties. For example, the most common oxygen isotope has 8 neutrons in the nucleus, but other isotopes have 9 or 10 neutrons. All three isotopes are colorless, odorless gases at room temperature. Each isotope has the chemical property of combining with a substance as it burns and even behaves the same in chemical changes in your body.

APPLY

Oxygen reacts, or undergoes a chemical change, with the hot filament in a light bulb, causing the bulb to burn out quickly. The element argon does not react with the filament, so a light bulb filled with argon does not burn out as quickly as one that contains oxygen. Three isotopes of argon occur in nature. Do you think all three isotopes have the same effect on the filament when used in light bulbs? Explain your reasoning.

How Can You Tell One Isotope from Another? You can identify each isotope of an element by its mass number. The **mass number** is the sum of the protons and neutrons in an atom. Electrons are not included in an atom's mass number because their mass is so small that they have very little effect on the atom's total mass. Look at the boron isotope models shown in **Figure 15** to see how to calculate an atom's mass number.

Protons: 5
Neutrons: 5
Electrons: 5
Mass number =
protons + neutrons = 10

Protons: 5
Neutrons: 6
Electrons: 5
Mass number =
protons + neutrons = 11

Figure 15 *Each of these boron isotopes has five protons. But because each has a different number of neutrons, each has a different mass number.*

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Explore

Draw diagrams of hydrogen-2, helium-3, and carbon-14. Show the correct number and location of each type of particle. For the electrons, simply write the total number of electrons in the electron cloud. Use colored pencils or markers to represent the protons, neutrons, and electrons.

To identify a specific isotope of an element, write the name of the element followed by a hyphen and the mass number of the isotope. A hydrogen atom with one proton and no neutrons has a mass number of 1. Its name is hydrogen-1. Hydrogen-2 has one proton and one neutron in the nucleus. The carbon isotope with a mass number of 12 is called carbon-12. If you know that the atomic number for carbon is 6, you can calculate the number of neutrons in carbon-12 by subtracting the atomic number from the mass number. For carbon-12, the number of neutrons is 12 − 6, or 6.

12	Mass number
−6	Number of protons (atomic number)
6	Number of neutrons

How Do You Calculate the Mass of an Element?

Most elements found in nature contain a mixture of different isotopes. For example, all copper is composed of copper-63 atoms and copper-65 atoms. The term *atomic mass* describes the mass of a mixture of isotopes. **Atomic mass** is the weighted average of the masses of all the naturally occurring isotopes of an element. A weighted average accounts for the percentages of each isotope that are present. Copper, including the copper in the Statue of Liberty (shown in **Figure 16**), is 69 percent copper-63 and 31 percent copper-65. The atomic mass of copper is 63.6 amu. Because the atomic mass is closer to 63 than to 65, you can tell the percentage of copper-63 is greater than the percentage of copper-65.

Most elements have two or more stable (nonradioactive) isotopes found in nature. Tin has 10 stable isotopes, which is more than any other element. You can try your hand at calculating atomic mass by doing the MathBreak at left.

Figure 16 *The copper used to make the Statue of Liberty includes both copper-63 and copper-65. Copper's atomic mass is 63.6 amu.*

MATH BREAK

Atomic Mass

To calculate the atomic mass of an element, multiply the mass number of each isotope by its percentage abundance in decimal form. Then add these amounts together to find the atomic mass. For example, chlorine-35 makes up 76 percent (its percentage abundance) of all the chlorine in nature, and chlorine-37 makes up the other 24 percent. The atomic mass of chlorine is calculated as follows:

$$(35 \times 0.76) = 26.6$$
$$(37 \times 0.24) = +8.9$$
$$35.5 \text{ amu}$$

Now It's Your Turn

Calculate the atomic mass of boron, which occurs naturally as 20 percent boron-10 and 80 percent boron-11.

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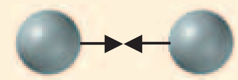
What Forces Are at Work in Atoms?

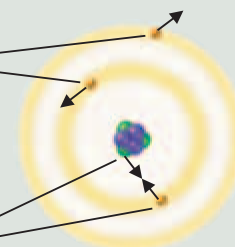
You have seen how atoms are composed of protons, neutrons, and electrons. But what are the *forces* (the pushes or pulls between two objects) acting between these particles? Four basic forces are at work everywhere, including within the atom—gravity, the electromagnetic force, the strong force, and the weak force. These forces are discussed below.

Forces in the Atom

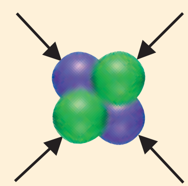
Gravity Probably the most familiar of the four forces is *gravity.* Gravity acts between all objects all the time. The amount of gravity between objects depends on their masses and the distance between them. Gravity pulls objects, such as the sun, Earth, cars, and books, toward one another. However, because the masses of particles in atoms are so small, the force of gravity within atoms is very small.



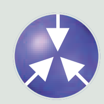
Electromagnetic Force As mentioned earlier, objects that have the same charge repel each other, while objects with opposite charge attract each other. This is due to the *electromagnetic force*. Protons and electrons are attracted to each other because they have opposite charges. The electromagnetic force holds the electrons around the nucleus.



Strong Force Protons push away from one another because of the electromagnetic force. A nucleus containing two or more protons would fly apart if it were not for the *strong force*. At the close distances between protons in the nucleus, the strong force is greater than the electromagnetic force, so the nucleus stays together.



Weak Force The *weak force* is an important force in radioactive atoms. In certain unstable atoms, a neutron can change into a proton and an electron. The weak force plays a key role in this change.



REVIEW

1. List the charge, location, and mass of a proton, a neutron, and an electron.
2. Determine the number of protons, neutrons, and electrons in an atom of aluminum-27.
3. **Doing Calculations** The metal thallium occurs naturally as 30 percent thallium-203 and 70 percent thallium-205. Calculate the atomic mass of thallium.

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Chapter Highlights

SECTION 1

Vocabulary

atom *(p. 304)*
theory *(p. 304)*
electrons *(p. 307)*
model *(p. 307)*
nucleus *(p. 309)*
electron clouds *(p. 310)*

Section Notes

- Atoms are the smallest particles of an element that retain the properties of the element.
- In ancient Greece, Democritus argued that atoms were the smallest particles in all matter.
- Dalton proposed an atomic theory that stated the following: Atoms are small particles that make up all matter; atoms cannot be created, divided, or destroyed; atoms of an element are exactly alike; atoms of different elements are different; and atoms join together to make new substances.

- Thomson discovered electrons. His plum-pudding model described the atom as a lump of positively charged material with negative electrons scattered throughout.
- Rutherford discovered that atoms contain a small, dense, positively charged center called the nucleus.
- Bohr suggested that electrons move around the nucleus at only certain distances.
- According to the current atomic theory, electron clouds are where electrons are most likely to be in the space around the nucleus.

Skills Check

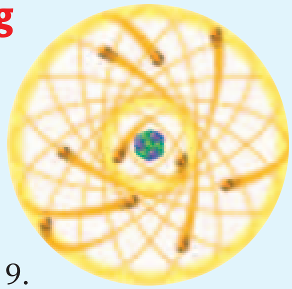
Math Concepts

ATOMIC MASS The atomic mass of an element takes into account the mass of each isotope and the percentage of the element that exists as that isotope. For example, magnesium occurs naturally as 79 percent magnesium-24, 10 percent magnesium-25, and 11 percent magnesium-26. The atomic mass is calculated as follows:

$$\begin{aligned}(24 \times 0.79) &= 19.0\\ (25 \times 0.10) &= 2.5\\ (26 \times 0.11) &= \underline{+\ 2.8}\\ & 24.3 \text{ amu}\end{aligned}$$

Visual Understanding

ATOMIC MODELS The atomic theory has changed over the past several hundred years. To understand the different models of the atom, look over Figures 2, 4, 6, 8, and 9.



PARTS OF THE ATOM Atoms are composed of protons, neutrons, and electrons. To review the particles and their placement in the atom, study Figure 11 on page 312.

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SECTION 2

Vocabulary

protons *(p. 312)*
atomic mass unit (amu) *(p. 312)*
neutrons *(p. 312)*
atomic number *(p. 314)*
isotopes *(p. 315)*
mass number *(p. 315)*
atomic mass *(p. 316)*

Section Notes

- A proton is a positively charged particle with a mass of 1 amu.
- A neutron is a particle with no charge that has a mass of 1 amu.
- An electron is a negatively charged particle with an extremely small mass.
- Protons and neutrons make up the nucleus. Electrons are found in electron clouds outside the nucleus.
- The number of protons in the nucleus of an atom is the atomic number. The atomic number identifies the atoms of a particular element.
- Isotopes of an atom have the same number of protons but have different numbers of neutrons. Isotopes share most of the same chemical and physical properties.
- The mass number of an atom is the sum of the atom's neutrons and protons.
- The atomic mass is an average of the masses of all naturally occurring isotopes of an element.
- The four forces at work in an atom are gravity, the electromagnetic force, the strong force, and the weak force.

Labs

Made to Order *(p. 570)*

internetconnect

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Visit the **HRW** Web site for a variety of learning tools related to this chapter. Just type in the keyword:

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TOPIC: Development of the Atomic Theory ***sci*LINKS NUMBER:** HSTP255
TOPIC: Modern Atomic Theory ***sci*LINKS NUMBER:** HSTP260
TOPIC: Inside the Atom ***sci*LINKS NUMBER:** HSTP265
TOPIC: Isotopes ***sci*LINKS NUMBER:** HSTP270

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Chapter Review

USING VOCABULARY

The statements below are false. For each statement, replace the underlined word to make a true statement.

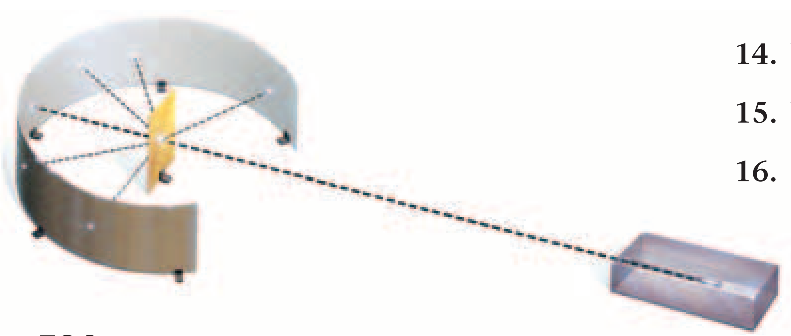
1. Electrons are found in the <u>nucleus</u> of an atom.
2. All atoms of the same element contain the same number of <u>neutrons</u>.
3. <u>Protons</u> have no electrical charge.
4. The <u>atomic number</u> of an element is the number of protons and neutrons in the nucleus.
5. The <u>mass number</u> is an average of the masses of all naturally occurring isotopes of an element.

UNDERSTANDING CONCEPTS

Multiple Choice

6. The discovery of which particle proved that the atom is not indivisible?
   a. proton **c.** electron
   b. neutron **d.** nucleus

7. In his gold foil experiment, Rutherford concluded that the atom is mostly empty space with a small, massive, positively charged center because
   a. most of the particles passed straight through the foil.
   b. some particles were slightly deflected.
   c. a few particles bounced back.
   d. All of the above



8. How many protons does an atom with an atomic number of 23 and a mass number of 51 have?
   a. 23 **c.** 51
   b. 28 **d.** 74

9. An atom has no overall charge if it contains equal numbers of
   a. electrons and protons.
   b. neutrons and protons.
   c. neutrons and electrons.
   d. None of the above

10. Which statement about protons is true?
    a. Protons have a mass of 1/1840 amu.
    b. Protons have no charge.
    c. Protons are part of the nucleus of an atom.
    d. Protons circle the nucleus of an atom.

11. Which statement about neutrons is true?
    a. Neutrons have a mass of 1 amu.
    b. Neutrons circle the nucleus of an atom.
    c. Neutrons are the only particles that make up the nucleus.
    d. Neutrons have a negative charge.

12. Which of the following determines the identity of an element?
    a. atomic number **c.** atomic mass
    b. mass number **d.** overall charge

13. Isotopes exist because atoms of the same element can have different numbers of
    a. protons. **c.** electrons.
    b. neutrons. **d.** None of the above

Short Answer

14. Why do scientific theories change?
15. What force holds electrons in atoms?
16. In two or three sentences, describe the plum-pudding model of the atom.

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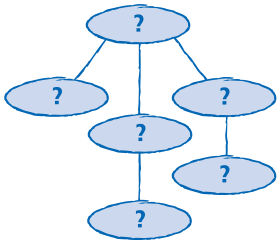
Concept Mapping

17. Use the following terms to create a concept map: atom, nucleus, protons, neutrons, electrons, isotopes, atomic number, mass number.



CRITICAL THINKING AND PROBLEM SOLVING

18. Particle accelerators, like the one shown below, are devices that speed up charged particles in order to smash them together. Sometimes the result of the collision is a new nucleus. How can scientists determine whether the nucleus formed is that of a new element or that of a new isotope of a known element?

19. John Dalton made a number of statements about atoms that are now known to be incorrect. Why do you think his atomic theory is still found in science textbooks?

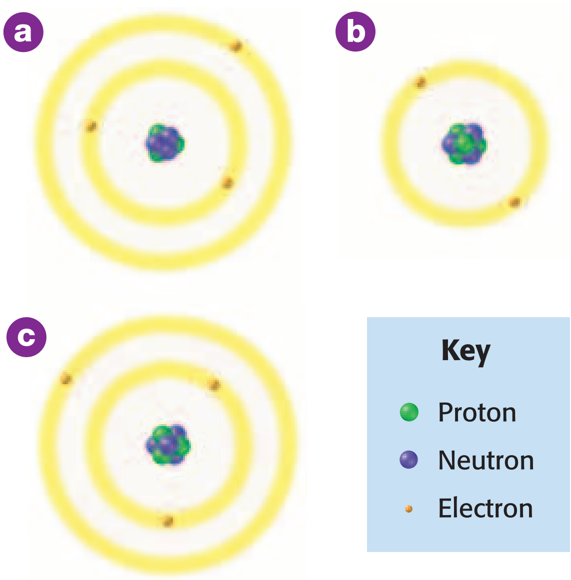
MATH IN SCIENCE

20. Calculate the atomic mass of gallium consisting of 60 percent gallium-69 and 40 percent gallium-71.

21. Calculate the number of protons, neutrons, and electrons in an atom of zirconium-90, which has an atomic number of 40.

INTERPRETING GRAPHICS

22. Study the models below, and answer the questions that follow:

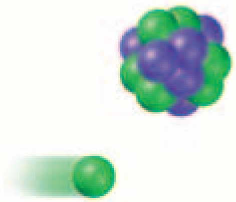


a. Which models represent isotopes of the same element?

b. What is the atomic number for (a)?

c. What is the mass number for (b)?

23. Predict how the direction of the moving particle in the figure below will change, and explain what causes the change to occur.



NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 303. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

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Water on the Moon?

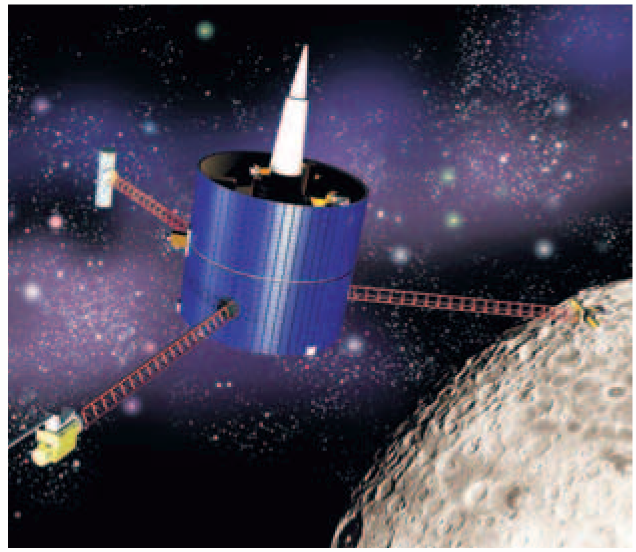
When the astronauts of the Apollo space mission explored the surface of the moon in 1969, all they found was rock powder. None of the many samples of moon rocks they carried back to Earth contained any hint of water. Because the astronauts didn't see water on the moon and scientists didn't detect any in the lab, scientists believed there was no water on the moon.

Then in 1994, radio waves suggested another possibility. On a 4-month lunar jaunt, an American spacecraft called *Clementine* beamed radio waves toward various areas of the moon, including a few craters that never receive sunlight. Mostly, the radio waves were reflected by what appeared to be ground-up rock. However, in part of one huge, dark crater, the radio waves were reflected as if by . . . *ice.*

Hunting for Hydrogen Atoms

Scientists were intrigued by *Clementine's* evidence. Two years later, another spacecraft, *Lunar Prospector,* traveled to the moon. Instead of trying to detect water with radio waves, *Prospector* scanned the moon's surface with a device called a *neutron spectrometer* (NS). A neutron spectrometer counts the number of slow neutrons bouncing off a surface. When a neutron hits something about the same mass as itself, it slows down. As it turns out, the only thing close to the mass of a neutron is an *atom* of the lightest of all elements, hydrogen. So when the NS located high concentrations of slow-moving neutrons on the moon, it indicated to scientists that the neutrons were crashing into hydrogen atoms.

As you know, water consists of two atoms of hydrogen and one atom of oxygen. The presence of hydrogen atoms on the moon is more evidence that water may exist there.



▲ *The* Lunar Prospector *spacecraft may have found water on the moon.*

How Did It Get There?

Some scientists speculate that the water molecules came from comets (which are 90 percent water) that hit the moon more than 4 billion years ago. Water from comets may have landed in the frigid, shadowed craters of the moon, where it mixed with the soil and froze. The Aitken Basin, at the south pole of the moon, where much of the ice was detected, is more than 12 km deep in places. Sunlight never touches most of the crater. And it is very cold—temperatures there may fall to −229°C. The conditions seem right to lock water into place for a very long time.

Think About Lunar Life

► Do some research on conditions on the moon. What conditions would humans have to overcome before we could establish a colony there?

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